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14. ABSTRACT

We purchased 2 dual wavelength ultrastable ultralow expansion glass cavities along with optics and electronics to stabilize 2 different laser systems used for DoD projects. The systems were constructed so that narrow bandwidth and stable long term locking could be achieved for 2 photon Rydberg atom excitation. Both systems were offset locked using a high bandwidth resonant electro-optic modulator so that the laser systems can be frequency tuned. Both systems have achieved spectral linewidths of less than 50 kHz and long term drift of <100 kHz per day.

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Report Title

Final Report: A Laser Stabilization System for Rydberg Atom Physics

ABSTRACT

We purchased 2 dual wavelength ultrastable ultralow expansion glass cavities along with optics and electronics to stabilize 2 different laser systems used for DoD projects. The systems were constructed so that narrow bandwidth and stable long term locking could be achieved for 2 photon Rydberg atom excitation. Both systems were offset locked using a high bandwidth resonant electro-optic modulator so that the laser systems can be frequency tuned. Both systems have achieved spectral linewidths of less than 50 kHz and long term drift of <100 kHz per day.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

"Sub-wavelength Microwave Electric Field Imaging using Rydberg Atoms," H.Q. Fan, S. Kumar, R. Daschner, H. Kubler, and J.P. Shaffer, DAMOP, Madison WI (2014).

"Quantum Assisted Electrometry using Electromagnetically Induced Transparency with Rydberg Atoms in a Vapor Cell," H.Q. Fan, S. Kumar, R. Daschner, H. Kubler, J. Sedlacek and J.P. Shaffer, DAMOP, Madison WI (2014).

"Using Rubidium Rydberg Atoms to Probe Atom-Surface Interactions," J. Sedlacek and J.P Shaffer, 2nd International Conference on Rydberg Atom Physics, Recife, Brazil (2014).

"Production of a 2-D Electron Gas Using Rydberg Atoms and Surface Adsorbates," J.P. Shaffer, B2 conference on Quantum Hybrid Systems, Tucson, AZ (2015). (invited)

"Atom-surface Studies with Rb Rydberg Atoms," Y. Chao, J. Sheng, J. Sedlacek and J.P. Shaffer, DAMOP, Columbus, OH (2015).

"Homodyne Microwave Electric Field Measurements Using Cs Rydberg Atoms in Vapor Cells," H. Fan, S. Kumar and J.P. Shaffer, DAMOP, Columbus, OH (2015).

"Interacting Rydberg Atoms in an Optical Cavity to Synthesize Coherent Collective States using Dipole Blockade," J. Sheng, J. Sedlacek, C. Ewel, H. Fan and J.P. Shaffer, DAMOP, Columbus, OH (2015).

Number of Presentations: 7.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Partially, because of the work that this grant enabled as connected to our DoD support, the PI was given an endowed chair (Homer L. Dodge Professor of Atomic, Molecular and Optical Physics) at OU. The chair was reviewed by an outside and internal committee.

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Jonathon Sedlacek	0.00	
Haoquan Fan	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**2**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Santosh Kumar	0.00
FTE Equivalent:	**0.00**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
James P. Shaffer	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

This grant was for installing and implementing 2 ultrastable high finesse Fabry-Perot cavities which were used to frequency stabilize the 2 Rydberg atom excitation laser systems we use for our DoD projects (ARO/DARPA and AFOSR). The first system functions at 852 nm and ~510 nm and is used for Cs Rydberg atom excitation. The second system operates at 780 nm and ~480 nm and is used for Rb Rydberg atom excitation. The 2 laser systems were stabilized to linewidths of < 50 kHz with frequency drift of < 100 kHz per day. The system used to lock each laser system was identical and also allowed the lasers to be tuned up to 750 MHz with a microwave signal generator to precisely fix the detuning. The systems were installed by graduate students and a postdoc who learned how to construct and operate this technology. The laser stabilization systems are an integral part of our lab setups and are used virtually every day.

The high finess (~20,000-30,000 depending on wavelength) Fabry-Perot cavities are made of ultra-low expansion glass. They are contained in a vacuum housing whose pressure is maintained by an ion pump. The vacuum housing sits in a radiation shield. The entire vacuum cavity is temperature regulated to <0.05 C. This passive stabilization leads to low drift of < 100 kHz per day. The only drawback is that the Fabry-Perot cannot be tuned which means that it was necessary to use an offset locking method which we did.

For each system, a small amount of light from a 852 nm (780 nm) diode laser is picked off from the output beam using a waveplate and polarizing beam splitting cube. This light is directed through a 10 GHz bandwidth fiber coupled electro-optic phase modulator (eom). The eom is modulated using an amplified signal from a microwave signal generator (1-3 GHz) that is capable of phase modulating its output. In this way, tunable sidebands, from 1-10 GHz, that are themselves modulated at .05-5 MHz, can be generated on the input laser beam. The light from the eom, namely the sideband, is used to generate a Pound-Drever-Hall signal by monitoring the reflected light from the ultra-stable Fabry-Perot cavity. The Pound-Drever-Hall signal is generated by taking the reflected light signal obtained from a fast photodiode and beating it against the 0.05-5 MHz phase modulation signal. This signal is fed back into the fast (10 MHz bandwidth) locking electronics of the diode laser system to lock the laser to the cavity. The diode laser can be tuned by tuning the primary sideband at 1-10 MHz. However, since the cavity free spectral range is 1.5 GHz, the tuning of the sideband is limited to 1/2 the free spectral range of 750 MHz. For Rydberg atom physics this is more than sufficient for experiments where the detuning from the Rydberg state does not have to be large.

For the ~510 nm (Toptica-SHG) and the ~480 nm (home built) laser systems, we used basically the same approach. However, both of these laser systems are based on the amplification and frequency doubling of a diode laser, the master diode laser was locked. This increased the locking bandwidth by avoiding the phase delay that limits the bandwidth of the 510 nm and 480 nm light that is generated in a multi-pass frequency doubling cavity. In addition, the master laser wavelengths of 1020 nm and 960 nm lie in the near infra-red closer to the 852 nm and 780 nm lasers so it was easier to obtain a high finesse for the Fabry-Perot cavities at both wavelengths by using multi-layer mirror coatings of high reflectivity.

We successfully implemented these setups and achieved <50 kHz laser spectral bandwidths along with low laser drift. < 100 kHz per day. The lasers can be positioned in frequency on the narrow Rydberg states each day by simple locking the sidebands to the cavity each morning at the same signal generator frequency, saving hours of time each day. In addition, the lasers can be parked onto the Rydberg atom transitions and data can be acquired for long periods of time without having to adjust the lasers even when performing precision measurement of RF electric fields using Rydberg atoms.

In conclusion, the proposed systems were installed successfully. They have been used for experiments on a daily basis since they were implemented. 2 students and 1 postdoc learned how to implement the systems and have used them for experiments since that time.

Technology Transfer

The work enabled by this award has lead partially to a DARPA sponsored SBIR phase I grant which involves the PI and the small business Cold Quanta to further develop RF electric field sensors based on Rydberg atoms. One of the installed devices is being used for our AFOSR project.